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Examining the Uses of Student-Led, Teacher-Led, and Collaborative Functions of Mobile Technology and Their Impacts on Physics Achievement and Interest

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Abstract

As mobile technology becomes more frequently used in science learning, understanding the relationship between student outcomes and the technology's pedagogical features is drawing increasing attention. This study focuses on one pedagogical feature—"who led the use." We first categorized 15 specific uses of mobile technology into three categories: student-led (i.e., initiated by the students and teachers have no or minimal influence on their use), teacher-led (i.e., initiated by teachers and the students have no or minimal impact on their use), and collaborative functions (i.e., both students and teacher need to play active roles in the use of mobile technology). We recruited 803 high school students who used a one-to-one tablet for 5 months and examined their use frequency, the functions used, and their physics outcomes. Results indicate a significant difference in the use frequency among the three categories. The collaborative functions were used with the highest frequency, whereas the student-led functions were used least. However, the student-led functions had a more significant effect size than the collaborative functions to predict both students' physics achievement and physics interest, while teacher-led functions failed to predict either of these outcome variables.

Keywords Mobile learning · Pedagogy · Constructivism · Teacher-led · Student-led · Collaborative · Science education · Tablet

Introduction

Due to its unique feature of portability and accessibility, mobile technology has been broadly adopted to promote students' science learning (Crompton et al., 2016; Zydney & Warner, 2016). Researchers found that mobile technology had been applied in many student-dominated situations such as accessing scientific experiments remotely, collecting and analyzing data, generating hypotheses, saving or searching notes, and communicating with peers online (Ahmed & Parsons 2013; Castropalacio et al., 2013; Lee, 2010; Purba & Hwang, 2017; Ryu et al., 2015). At the same time, teachers prefer to use mobile devices on their own for tasks such as preparing lessons, correcting student homework, or even assigning tests in the classroom (Zhai et al., 2016). In these activities, teachers dominate the use of the technology.

Not surprisingly, in some situations, both students and teachers play dominant roles in using mobile technology. For instance, in a flipped science classroom, teachers upload learning guide materials (e.g., text, pictures, video) into an e-cloud, while students use personal iPads to preview or review the sources after school to remediate learning at their own pace (Palloff & Pratt, 2002). In this situation, teachers decide the learning content, and students dominate the pace of learning. In a more broad review of mobile technology in science learning, we found that even though the technology was used in these varied approaches, the impact on students' achievement (Lin et al., 2013; Liu et al., 2017) or interest (González et al., 2014; Hochberg et al., 2018) was reported in many studies.

Although the different approaches to using mobile technology are well known and their promise is recognized, we do not know how frequently different use approaches are applied in the science classroom (Lindsay, 2016). Knowing how often students and teachers use these functions is important because

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if the approaches are seldom applied in real classroom learning, then it makes no sense for schools to integrate them into the curriculum at this time, even though the technology displays great promise. Also, rarely have studies systematically compared the effect sizes of the three approaches to students' achievement and learning interest (Zydney & Warner, 2016). Understanding the different effect sizes among these approaches will aid school leaders, science instructors, and technology designers in knowing how best to develop and implement the technology in the education setting (Hamilton et al., 2016).

In the current study, we focus on one pedagogical characteristic—learning agency—defined as "who led the use of these functions," which is a vital feature of the three approaches mentioned above. The primary purpose of the current study is to examine how this pedagogical characteristic impacts the frequency of using mobile technology and how this characteristic affects the effect size of using mobile devices on students' learning achievement and interest. We argue that the results may meaningfully guide the development and use of future multifunctional mobile systems.

A Model of Student-Led, Teacher-Led, and Collaborative Functions of Mobile Technology

The Rationale of the STC Model

The purpose of this study stems from a fundamental question for technology in education—why do we adopt educational technology (Kotrlik & Redmann, 2008)? The ultimate answer seems apparent—to promote student learning. However, in the early stage when technology was adopted in education, students usually had no direct access to use the technology due to many factors such as cost. Instead, the technology was mainly used by teachers to directly support their teaching activities. For example, when PowerPoint was first introduced to education, teachers spent the time to made slides to primarily help themselves organize and better display the teaching material. In this situation, students usually were passively influenced by the technology, while teachers decided when to use and how to use the technology. The rationale of adopting technology in this way is based on an assumption—to promote student learning through supporting teachers' activities. We note this approach of technology use features a "Teacher-led" pedagogy, which means it is the teachers who initiate, decide, and lead the use of technology, while students usually have no or minimum influence to the use of technology.

To date, there is much evidence that when classrooms did adopt technology, the adoption experienced a shift from the teacher-led "sage on the stage" to a student-led "guide on the side" orientation (Groves & Zemel, 2000). As opposed to teacher-led technology, the student-led function grants students more agency to initiate and manipulate the technology uses in their learning for their own purposes. For example, the simulation lab features such a student-led pedagogy. During using such technology, students not only have access to the technology but also, initiate, decide, and lead each step of the use. In this situation, students actively lead the use, while teachers mainly play an assistant role.

We notice that this pedagogical feature is not only associated with the type of technology but also how the technology is used. One given technology could have different approaches to be used in a classroom setting. For example, Kershner et al. (2010) differentiated the classroom uses of the whiteboard as teacher-led and student-led. Based on constructivism in education (Staver, 1998), the two kinds of functions suggest how the technology acts in education—teachers take an active role of using the whiteboard to facilitate student learning, or students take a central role in using the whiteboard for learning directly. Likewise, mobile technology, one of the most popular techniques in education, functions with both teacher-led and student-led pedagogy. For example, mounting apps installed on mobile devices are used to help teachers manage students' assignments, monitor their progress, or prepare teaching materials to indirectly support student learning, thus featuring a teacher-led pedagogy (Mac Callum & Jeffrey, 2014). In contrast, other apps can directly aid students actively involving in learning activities such as note-taking, modeling or argumentation (Huang & Chiu, 2015). The research mentioned above demonstrates that the mobile technology in the classroom can facilitate student learning with different pedagogy. The success of these different uses of functional apps thus suggests the soundness of the fundamental philosophy of adopting mobile technology in education.

In addition to the perspective of teacher-led or student-led, we also find a mutual use of mobile devices between teachers and students—a collaborative function. In using the collaborative function, both teachers and students play an active role—they have the opportunity to decide when and how to involve in the use of the mobile technology on their own. This function is usually initiated by either the teacher or the students and requires a response from the counterpart (Wette, 2015), thus granting opportunity for both teachers and learners to play an active role. For example, Koroleva (2016) surveyed 3194 students aged 16–18 years old in Russian schools and found that students were frequently given homework assignments online by their teachers. Students needed to use mobile phones or PDAs to upload their completed homework, which was then reviewed and evaluated by the teachers. In this case, the technology supported the teachers by summarizing the statistical information of students (e.g., the ratio of correct answers, the time students used to complete the homework). Also, it offered convenience for

students with various functions, such as online help and immediate noting. This is a typical example of a collaborative function of mobile technology, in which the teachers initiated the task, the students completed the work, and lastly the teachers corrected it all through the mobile devices. In this learning process, the mobile technology played the role of connecting the student learning activity with the teacher supportive activity (Roschelle & Teasley, 1995).

In light of the pedagogical approaches mentioned above, we developed a STC (i.e., student-led, teacher-led, and collaborative functions) model to illustrate the underlining mechanics regarding how student-led, teacher-led, and collaborative functions of mobile technology enhance learning. In this model, we explicitly differentiate between two kinds of activities—student activity and teacher activity that serve the learning goal. We regard the student activity as directly contributing to a learning goal, whereas the teacher activity acts by supporting student activity. The mobile device enhances this cognitive process via three functions—student-led, teacher-led, and collaborative, each of which directs to a specific activity (Fig. 1). The model is grounded in constructivism, which argues that learning is ideally a learner-centric process in which students lead their learning and knowledge construction by themselves (Tsai, 2001).

From the constructivist perspective, students employ mobile technology, as needed, to assist themselves in the construction process. The teachers' role in learning is to facilitate student self-construction rather than to transmit knowledge (Reychav & Wu, 2015). Therefore, in the constructivist's view, teachers mainly use mobile technology to assist students' self-directed learning practice (Romrell et al., 2014). Although in those teacher activities where teachers primarily use teacher-led functions, if not collaborated with students, it appears those supports to students gaining from mobile technology uses are indirectly in a constructivist framework. However, other approaches, such as the objectivist approach, might still regard these instructor-centric activities using teacher-led functions as an effective knowledge transformation process (Jonassen, 1991). This is also an assumption that this study wants to verify.

Literature Review

According to our review of the literature, although no study explicitly compared all of the three categories of functions outlined in our STC model, some studies focused on individual functions (i.e., student-led, teacher-led, and collaborative functions). In 2010, Alpay and Gulati (2010) proposed a student-led use of podcasts in engineering education and found positive outcomes regarding promoting skill development, community identity and educational awareness within learning environments. In this learning process, students led the uses of podcasts on their own, for example, sharing views or disseminating information. Another study conducted by Davies (2014) examined a student-led use of Apple iPads in higher education. The researcher designed a tutorial group in which students attended a series of iPad-supported activities. He found the student-led mobile platform advanced students' engagement with learning activities and increased student self-confidence. In addition, Makos et al. (2015) designed a student-led "Like" button and a linking tool in an interactive discussion-based learning environment to scaffold learner behaviors and found positive outcomes of engagement and cognitive complexity for student online discussion.

In addition to studies focusing on student-led functions, we also found studies of teacher-led functions of mobile technology. For example, Haya et al. (2015) employed a Social Learning Analysis toolkit to enhance teachers' inquiry of the lesson plan. The teacher-led toolkit was designed to help teachers better understand the organization of student learning processes and to facilitate student reflection on learning. The researchers found this toolkit furthered teachers' insights into and analyses of the technology-enhanced learning activities. Akcaoglu and Bowman (2016) found that students in a college classroom who enrolled in an instructor-led Facebook group reported greater learning interest and value in the learning content and perceived more engagement in the course on their part as well as that of their instructors. In a more recent study (Foshee et al., 2016), to foster college students'

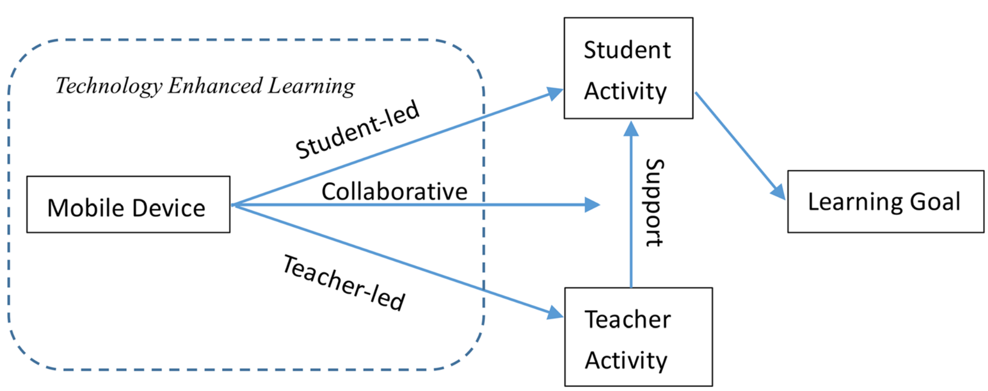

Fig. 1 The STC model of student-led, teacher-led, and collaborative functions of mobile technology

mathematics performance, researchers integrated an adaptive, individualized, and mastery-based technology-enhanced learning into the classroom with a teacher-led instruction approach. The results indicate that the instruction method remediated students' math learning and positively affected students' confidence regarding academic ability and competence.

These prior studies provide some data related to the use of student- and teacher-led functions of mobile technology. However, there is virtually no data pertaining to the collaborative functions of mobile technology, as only one study, the aforementioned by Koroleva (2016), focused on this aspect. We also note that virtually very few of the studies focused on physics learning. In addition, prior studies did not compare the effects of the three functions. The current study aims to fill in these gaps.

The Current Study

This study took place in a high school in a medium-sized city in China. To revolutionize student learning, the school leaders initiated a one-to-one technology reform among the teachers and students. They developed an interactive management learning system (IMLS), which was then installed with relevant apps on the tablets of each teacher's and student's. This multifunction IMLS formalizes an e-learning environment in which students and teachers could access the interactive classroom whiteboard and an instructional e-cloud. The tablet within the e-learning environment, supported by classroom Wi-Fi or home internet, connects the in-classroom learning to after-school learning. Students and teachers could communicate freely online by tablets even after school. The tablets with the IMLS provide teachers with functions such as class control, resource management, response collection, screen display, and instructional preparation, whereas students have access to such functions as resource sharing, homework assigning and collection, and online assistance. A survey study (Zhai et al., 2018b) indicates that the tablets were frequently used in physics learning both in the classroom and after school—79.70% of the students reported using the tablets in more than half of their physics classes per week and 84.18% of students reported using them more than three times per week after school for physics learning.

To pinpoint the common uses of the tablets in physics learning, Zhai and his colleagues (2018b) surveyed the students and physics teachers in this school and collected data on 20 frequently used specific uses, both in class and after school (for specific uses, refer to Table 1). Drawing upon their prior study, we picked up those 20 specific uses and categorized them as one of the three functions: a *student-led function*, a *teacher-led function*, or a *collaborative function*. Functions classified as student-led are those initiated by the students, and teachers are assumed to have no or minimal influence on their use. An example of a student-led function includes the *build incorrect item set*, in which students add items to the item sets and include tags or notes to annotate the mistakes they make and lessons they learn, all without input from teachers. Teacher-led functions are those initiated and driven by teachers only, and students are assumed to have no or minimum input. The *screen display* is an example of a teacher-led function. Using the *screen display*, a teacher displays a student's screen on the whiteboard to show the student's work or drawing. Often, it is up to teachers to strategically determine when and whose work is to be displayed; in this sense, students cannot control whether their work will be selected or not. Finally, collaborative functions are defined as those in which both students and teacher need to play active roles, as either the teacher provides resources that students are then able to respond to or students submit such things as progress reports, to which teachers can respond, all through mobile devices. *Use learning guide* is an example of a collaborative function. For this function, after school, students decide to watch the study guide (e.g., micro videos) that the teacher provides and then the teacher decides to check the statistical report of student use and adjusts his/her instruction accordingly. Because of the reciprocal nature of the process, this function is considered collaborative.

In this study, a high school teacher and a researcher categorized each of the available uses with sufficient inter-rater reliability ($r_\tau = 0.75$, $p < 0.001$). Eventually, five specific uses are excluded because they are not typically attributed to only one of the three categories, as the type of use is dependent on the specific situation. The remaining 15 uses are five for teacher-led, five for student-led, and five for collaborative functions (refer to Table 1).

This study asks two research questions:

1. How often do high school students and teachers use the three categories of mobile functions in physics learning?
2. Does the frequency of using the three different categories of mobile functions predict high school students' achievement and interest in physics?

Methods

Participants

We recruited 831 10th-grade students (ranging from 14 to 16 years old) from 28 classrooms in this 5-month study. After deleting the invalid data (details refer to Zhai et al., 2018b), 803 students were available for analysis. Of these, 409 are male and 394 are female. These 28 classes were parallel with each other regarding the students' achievements

Table 1 Student-led, teacher-led, and collaborative functions for mobile technology (adapted from Zhai et al., 2018b)

Functions	Mobile technology-supported instruction	S-T
Screen broadcast	Students watch slides or other material offered by teachers from mobile device screens. They take screenshots and store the content in their own files	C
Picture uploading	When teachers assign subjective work to students, they require students to upload pictures that are taken of student work, tests, or drawings to teachers immediately during class	T
Doodling	When teachers broadcast screens or assign subjective work, students are required to write or draw directly on the screen and store or submit	T
Clicker	When teachers have formative questions, quick tests, or votes for students to monitor or adjust the instructions, they will ask students to respond by using clickers	T
Class test	When teachers want to monitor students' learning outcomes during class or at the end of the class, they will issue a class test to students. Teachers can retrieve statistical results immediately	T
Screen display	Teachers display a student's screen onto the whiteboard to show the student's work or drawing. Students can explain their work at the same time under requirements	T
Use learning guide	Students can watch guided resources (pictures, videos, simulation experiments, etc.) once they need help. Teachers can check the statistical report and adjust their instruction	C
Preview learning guide	Students use the resources in the learning guide (texts, pictures, videos, simulation experiments, etc., provided by teachers for class usage) to prepare for class	C
Review learning guide	Students use resources in learning guide (texts, pictures, videos, simulation experiments, etc. which may be used in class) to review the academic content. Teachers can check the statistical report and adjust their instruction	C
My homework	If the homework consists of objective multiple-choice items, student answers can be statistically summarized for teachers automatically. If the homework consists of subjective items, students can complete them on paper and upload them by taking pictures. Teachers correct or give comments on them directly. Students can also add items to the incorrect items set or check the homework guide	C
My textbook	Students use the textbook for preparation, review, and searching or as a tool for learning. It is easy to insert tags, highlight, etc.	S
Mindmap	Students use this function especially at the end of a chapter for building knowledge structure. It can also be used to make notes	S
Class notes	Students review class notes after class, which can be easily modified, reorganized, tagged, searched, etc.	S
Build incorrect items set	Students add items to the incorrect items set and add tags or notes to them	S
Use incorrect items set	Students review or manage the incorrect items set in the device, such as highlighting, marking, searching, and indexing	S

S student-led function, *T* teacher-led function, *C* collaborative function

when they entered the high school. Each student received his or her tablet installed with the IMLS and was allowed to use the tablet in class and bring it home. We measured the students on their physics learning the year before the study as well as immediately after the study was completed. In addition, they completed two online surveys (to be described next).

Measures

Mobile Technology Survey (Mobile Function Predictors) Zhai et al. (2018b) previously developed the survey used in the present study. They first reviewed the manual documents for supporting the mobile uses. Then, they interviewed the lead physics teacher and gathered inputs from the other physics teachers in the school regarding the using frequency and how to use the mobile technology. Based on those information, they developed a survey and piloted it with 23 grade 10th high school physics students. Afterwords, we revised the survey. They asked students to indicate, using a 5-point self-report rating scale, how frequently they used each of the functions. The in-class use question stem is "How frequently did you use the following functions in the physics classroom?", with response options that include five options: (A) in every class, (B) in most classes, (C) in about half of the classes, (D) in less than half of the classes, or

(E) seldom. The after-school use question stem is “How frequently did you use the following functions in after-school physics learning?” with response options that include five options: (A) every day, (B) two to three times a week, (C) once a week, (D) once a month, or (E) seldom.

Cronbach’s alpha (internal consistency) was computed for each set of uses and was found to be 0.93, 0.90, and 0.80 for student-led, teacher-led, and collaborative functions, respectively. We also carried out a confirmatory factor analysis (CFA) on the mobile technology function uses serving the purposes of (1) verifying how well the STC model categorization of the functions fit the data and (2) confirming the coding reliability. The CFA results yielded a good model fit as $x^2/df = 4.59$ ($p < 0.001$), RMSEA = 0.067 ($p < 0.001$), CFI =0.965, and TLI = 0.957.

Physics Achievement (Outcome 1) A physics achievement test was administered to students by the school district at the beginning of their 10th-grade academic year as well as at the end of the first semester (5 months later). The first test indicates the placements of the students when they entered the high school, and the second test examines the progress of student achievement after 5 months of physics learning. Both tests have identical item formats: 10 multiple-choice items, three short-answer essay items, and four open-ended items. The pre-test was controlled as covariance, and the post-test was regarded as the indicator of physics achievement in the study. The Cronbach’s coefficient for the two tests is 0.79.

Physics Interest (Outcome 2) Zhai et al. (2018b) developed a four-item survey, which was a revised version of a survey used in Lamb et al. (2012) study to measure high school students’ interest in physics. The survey was administered at the end of the semester, at the same time that the mobile functioning survey was administrated. All items are self-reported 5-point rating scales. An example of an item stem includes “Compared to pursuing test scores, I prefer the inquiry process of learning physics,” with responses ranging from 1 = strongly disagree to 5 = strongly agree. Cronbach’s alpha is 0.85.

Data Analysis

Because students within one classroom may have more in common with each other than with students in another classroom (e.g., classroom culture, teaching styles) and therefore induce dependencies in the data, we used multilevel hierarchical linear models (HLMs) with random intercepts (Raudenbush & Bryk, 2002) to analyze the data. For ease of interpreting the magnitude of the effects, we standardized all variables into z scores before analysis ($M = 0$, SD = 1). Following we introduced two models that were used in the study. The first model helps to determine whether an HLM model is necessarily used in the analysis. The second model introduces the independent variables used in the analysis.

Baseline ICC Estimates Our first model is a baseline intercept-only model (i.e., with no predictors) that serves to determine the intra-class correlation (ICC) among students within classes (i.e., the magnitude of the classroom membership effect on the outcome; Raudenbush & Bryk, 2002):

$$Y_{sc} = \gamma_{00} + a_c + e_{sc},$$

where

a_c i.i.d. normal (0, τ^2) and
e_{sc} i.i.d. normal (0, σ^2).

In the model above, Y_{sc} is the score of the sth student in the cth classroom on the outcome variable (post-score or physics interest), which is a function of γ_{00} as the grand mean among all classes, with a_c as the deviation between the student’s classroom mean and the grand mean (i.e., the mean of the average scores of all the classes) and e_{sc} as the deviation between a student’s score and their classroom’s mean. Considering that our students are in parallel achievement classes, it is possible that the variance of student achievement between classes might be small. However, the progress of student achievement might also be affected by class-level confounding variables. To more precisely calculate the ICC for the post-score, we control for the prescore in this model as well.

Random Intercept and Slope Model Since students were distributed in 28 classes, we selected using a two-level random intercept and slope model, which allows for each class to have its own mean achievement and effect sizes. For this two-level model, we still regarded the student post-score as the dependent variable. In the first-level model, we proposed five predictors as follows: the students’ gender, the prescore, the mean frequency of the student-led uses, the mean frequency of the collaborative uses, and the mean frequency of the teacher-led uses. In the second level, to take into account the difference of the climate of using mobile technology among classrooms, we proposed the mean uses of mobile technology in physics learning for each class as a predictor. The mean use is calculated by the average frequency of the three categories for each class. The equation of the combined model is as follows:

$$Y_{sc} = \gamma_{00} + \gamma_{01}{}^*(\text{Class use})_c + \gamma_{10}{}^*(\text{Gender})_{sc} + \gamma_{11}{}^*(\text{Class use})_c{}^*(\text{Gender})_{sc} + \gamma_{20}{}^*(\text{Prescore})_{sc} + \gamma_{21}{}^*(\text{Class use})_c{}^*(\text{Prescore})_{sc} + \gamma_{30}{}^*(\text{Student-led})_{sc} + \gamma_{31}{}^*(\text{Class use})_c{}^*(\text{Student-led})_{sc} + \gamma_{40}{}^*(\text{Collaborative})_{sc} + \gamma_{41}{}^*(\text{Class use})_c{}^*(\text{Collaborative})_{sc} + \gamma_{50}{}^*(\text{Teacher-led})_{sc} + \gamma_{51}{}^*(\text{Class use})_c{}^*(\text{Teacher-led})_{sc} + a_c + e_{sc}$$

In this model, γ_{00} is the intercept and coefficient γ_{01} is the fixed slope of the second-level predictors. The γ_{k0} ($k = 1, 2\ldots5$)

are the fixed slopes of the first-level predictors, whereas the γ_{k1} ($k = 1, 2\ldots5$) are the interactions between the first-level predictors and the second-level predictors. The a_c is the deviation between the student's classroom mean and the grand mean, and e_{sc} is the deviation between the student's score and the classroom's mean.

Results

The Frequency of STC Uses of Mobile Technology in Physics Learning

The frequency of mobile technology use for each of the different types of functions can be seen in Fig. 2. To better illustrate and interpret these results, we adopted Zhai et al. (2018b) criteria to rank high, medium, and low uses as used in more than half of the classes or more than two to three times a week after school, used in less than half of the classes or once a week after school, and seldom used in classes or less than once a week after school, respectively. Concerning that we have five specific uses within each of the three categories, we averaged the percents of students who selected the high, medium, and low use for each of such specific uses within three categories, respectively. Our results suggest that the collaborative functions are most preferred, as it is shown that averagely 68.14% students referred them as high use, whereas only 23.86% students indicated that the student-led functions are of high use. The medium uses are identical for the three categories, whereas the student-led and teacher-led functions account for the majority of low use as that averagely 62.32% and 52.75% of students indicated, respectively. In sum, though the frequency of use diverse across the three categories, the mobile technology is frequently used in students' daily physics learning.

To further examine whether the use frequency differ across the three categories of mobile learning functions, we conducted a one-way between-subjects ANOVA analysis. There is a significant effect of the STC framework on the frequency of uses at the $p < 0.001$ level for the three categories [F (2, 2406) = 443.540, $p = 0.000$]. Post hoc comparisons using a least significant difference (LSD) test indicates that the mean score for the collaborative functions ($M = 3.77$, SD = 0.82) is significantly higher than both the teacher-led functions ($M = 2.68$, SD = 1.12) and student-led functions ($M = 2.21$, SD = 1.24). The student-led functions are the least frequently used functions. Taken together, these results suggest that the average frequency of use for the mobile device significantly differs across the three categories in physics learning. Specifically, our results suggest that for mobile technology, the collaborative functions are most frequently used in physics learning, and the student-led functions are used with the lowest frequency, whereas the teacher-led functions are of a medium frequency of use.

The Impacts of STC Uses of Mobile Technology on Physics Achievement and Interest

Impacts on Physics Achievement We conducted an analysis of variance on achievement scores using the class as a fixed independent variable and controlling for the prescore and found that there is a significant main effect of class on student post achievement ($\chi^2 = 67.82$, $df = 27$, $p < 0.001$). Additionally, the baseline multilevel intercept-only model shows that there is a moderate ICC = 0.05, which means 5% of the variance in student achievement can be explained by which class the student is in. Therefore, we further examined the treatment of the three categories of functions by a random intercept model.

The main results of the random intercept model are provided in Table 2. After controlling for students' gender and the prescore, student-led functions ($\gamma_{30} = 0.20$, $p < 0.001$) and collaborative functions ($\gamma_{40} = 0.08$, $p < 0.05$) significantly predict students' physics achievement, but teacher-led functions fail

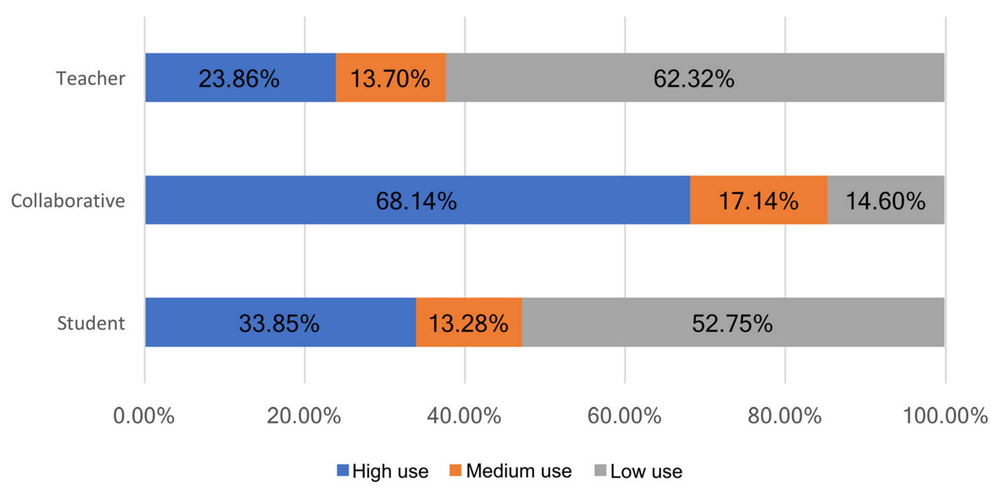

Fig. 2 The percentages of high, medium, and low use of student-teacher-led functions of mobile technology

Table 2 The effects of the STC uses on students' physics achievement

Fixed effect	Coefficient	SE	*T* ratio	*df*	*p* value
For intercept$_1$					
Intercept$_2$, γ_{00}	0.014	0.040	0.352	26	0.728
Mean use, γ_{01}	0.027	0.036	0.758	26	0.455
For gender slope					
Intercept$_2$, γ_{10}	− 0.055	0.029	− 1.900	791	0.057
Mean use, γ_{11}	− 0.002	0.032	− 0.061	791	0.952
For prescore slope					
Intercept$_2$, γ_{20}	0.722	0.035	20.702	791	**0.000**
Mean use, $\boldsymbol{\gamma_{21}}$	− 0.104	0.038	− 2.765	791	**0.006**
For student-led slope					
Intercept$_2$, γ_{30}	0.196	0.045	4.371	791	**0.000**
Mean use, γ_{31}	0.014	0.041	0.348	791	0.727
For collaborative slope					
Intercept$_2$, γ_{40}	0.076	0.028	2.713	791	**0.007**
Mean use, γ_{41}	0.003	0.032	0.079	791	0.937
For teacher-led slope					
Intercept$_2$, γ_{50}	0.030	0.038	0.791	791	0.429
Mean use, γ_{51}	− 0.098	0.045	− 2.176	791	**0.030**
Random effect	SD	Variance	*df*	x^2	*p* value
Intercept$_1$, e_{sc}	0.171	0.029	26	71.44	**0.000**
Level 1, a_c	0.684	0.468			

The *p* value in bold indicates a significance at .05 level

Table 3 The effects of the STC uses on students' physics interest

Fixed effect	Coefficient	SE	*T* ratio	*df*	*p* value
For intercept$_1$,					
Intercept$_2$, γ_{00}	− 0.004	0.039	− 0.114	26	0.911
Mean use, γ_{01}	0.185	0.047	3.920	26	**0.001**
For gender slope					
Intercept$_2$, γ_{10}	− 0.136	0.037	− 3.664	791	**0.000**
Mean use, γ_{11}	0.071	0.040	1.765	791	0.077
For prescore slope					
Intercept$_2$, γ_{20}	0.010	0.027	0.386	791	0.699
Mean use, γ_{21}	− 0.026	0.033	− 0.772	791	0.441
For student-led slope					
Intercept$_2$, γ_{30}	0.174	0.061	2.826	791	**0.005**
Mean use, γ_{31}	0.034	0.074	0.464	791	0.642
For collaborative slope					
Intercept$_2$, γ_{40}	0.104	0.039	2.642	791	**0.009**
Mean use, γ_{41}	0.038	0.040	0.962	791	0.337
For teacher-led slope					
Intercept$_2$, γ_{50}	0.092	0.054	1.700	791	0.089
Mean use, γ_{51}	− 0.062	0.058	− 1.061	791	0.289
Random effect	SD	Variance	*df*	x^2	*p* value
Intercept$_1$, e_{sc}	0.123	0.015	26	38.02	0.060
Level 1, a_c	0.920	0.847			

The *p* value in bold indicates a significance at .05 level

to offer that prediction ($p > 0.05$). Results suggest that within one standard deviation increase of student-led functions of mobile technology use, student achievement increases 0.20 standard deviations. When the collaborative functions use increases one standard deviation, student achievement increases 0.08 standard deviations. Though no significant main effect is found for the use of teacher-led functions, its interaction with the mean use of each class is significant ($\gamma_{51} = -0.10$, $p < 0.05$). That means, in the lower use classes, the teacher-led functions could positively predict student achievement. In addition, we found that the prescore significantly predicts student physics achievement ($\gamma_{20} = 0.72, p < 0.001$), as well as its interaction with the mean use of mobile technology in each classroom ($\gamma_{21} = -0.10, p < 0.01$). This result indicates that in the classrooms with average lower uses of mobile technology, the prescore is more likely to be significantly related to the post-score. Additionally, we did not find a significant effect size of student gender on achievement. In the final model, the second-level variable accounts for 6% of the total variance, indicating that the classroom accounts for 6% of the variance for the students' physics achievement.

Impacts on Physics Interest With respect to student physics interest as the dependent variable, the results of the ANOVA show that classroom membership had a significant effect on student physics interest ($\chi^2 = 63.09$, $df = 27$, $p < 0.01$). The ICC = .04, indicating that 4% of the variance in student physics interest can be explained by which classroom the student was in. The results of the effects on physics interest can be seen in Table 3. After controlling for student gender and prescore, frequency of using student-led functions ($\gamma = 0.17$, $p < 0.01$) and collaborative functions ($\gamma = 0.10$, $p < 0.01$) both have a significant positive relationship with students' physics interest, whereas teacher-led functions ($\gamma = 0.09$, $p > 0.01$) do not demonstrate a significant relationship with students' physics interest. The results suggest that within one standard deviation increase in the frequency of using student-led functions, students' physics interest increases by 0.17 standard deviations, and when collaborative functions use increases by one standard deviation, students' physics interest increases by 0.10 standard deviations.

In addition to the main findings, we also found that the average uses of mobile technology in each classroom ($\gamma = 0.19$, $p < 0.01$) and student gender ($\gamma = -0.14$, $p < 0.01$) are two predictors for student interest, after controlling for the other variables (shown in Table 3). This result indicates that within one standard deviation increase of average uses of mobile technology in the classroom, student physics interest increases by 0.18 standard deviations, and the male student scores indicate higher physics interest, compared to the female

student scores, by 0.14 standard deviations. The second-level variable accounts for 2% of the total variance.

Discussion and Conclusion

This study theorized the functions of mobile technology in physics learning into three categories and tracked 803 high school students' frequency of engaging with 15 specific uses within a multifunctional IMLS in physics learning and examined the impacts of the three categories of functions on student physics achievement and interest. The results contribute to the literature in four aspects: first, prior studies have explored the factors that influence the uses of mobile technology (e.g., age, gender, perceived usefulness; Han & Shin, 2016), but no study identified "who led the use" as the main factor. This study dug into the roles of teachers and learners as well as their interactive relationship with mobile technology to help us better understand how the mobile devices are used in physics learning. Previous research indicates mobile technology is frequently used in physics learning, both in the classroom and after school. However, it is not used equably: Teachers and students have their own preference for specific uses (Zhai et al., 2018b, 2018c). In the present study, we observed that the highest uses were collaborative functions, which were of significantly higher use than both teacher-led and student-led functions. This result reflects one of the unique strengths of mobile technology in physics learning, as it appears that the mobile devices frequently connect the teachers and students to formulate an interactive learning setting. Though we cannot assert that the mobile technology leads to more interactive learning activities between students and their teachers than would occur in a classroom without such technology, mobile devices do play a significant role in conveying information and feedback between teachers and learners (Barron, 2000). This finding is encouraging for further implementation of mobile technology to physics learning in the future.

Second, we also noted that students do not play a leading role compared to teachers in the uses of mobile devices in physics learning. The collaborative functions are dominant in terms of mobile technology use by both teachers and students. However, based on the fact that the student-led functions were ranked as the lowest uses among the three categories, it is likely that the students did not play an equally active role to that of teachers in use of collaborative functions. This finding motivates us to better understand the roles students play in physics learning with mobile technology, especially because students have a potential space to reach a higher level in which they could play the dominant role in using mobile technology. In contrast, we see teachers acting in the principal role of leading the uses of mobile technology. This finding confirmed prior studies (Ifenthaler & Schweinbenz, 2013) in which the authors argued that active use of mobile technology in learning was dependent on teachers' acceptance and intention. This finding helps us understand that a high frequency of tablet use in physics learning is at least partially due to the teachers' high acceptance. We speculate that the professional training the school provided to the teachers and the ease of use of this IMLS might also be critical factors (Zhai et al., 2018b) that lead to the teachers' enthusiastic acceptance of the technology.

Third, though it seems that the students do not play a critical role in leading the using frequency of mobile technology, the student-led functions significantly predict the students' physics achievement and interest. In contrast, the teacher-led functions do not have a significant correlation with student physics achievement and interest. The collaborative functions, though smaller in effect size than the student-led functions, also have a significant positive correlation with student learning. Based on these findings, we speculated that the effect of the mobile technology is correlated with whether the students actively dominated the uses. This speculation is consistent with our theoretical model and its basis, constructivist theory (Jonassen et al., 1999; Zhai et al., 2018a). Drawing upon the fact that students are not taking in dominant roles in mobile technology use, our result suggests that learner-centric uses of mobile technology should be encouraged in the future. In addition, technology designers and producers should design mobile apps or relevant hardware around the learners, rather than around the teachers, to facilitate an app's impact on students' learning. Our findings also point to learner-centric activities as the most effective deployment of mobile devices in learning. Awareness on the part of both teachers' and students' roles in the learner-centric technology may lead to better implementations and outcomes of mobile technology in their classroom.

Another interesting finding is that the interaction between teacher-led functions and the average uses in each classroom significantly predicts physics achievement and interest, despite of no significant main effect of teacher-led functions. Further analysis indicates that in each classroom with lower average uses, the teacher-led functions are positively correlated with students' physics achievement and interest. In contrast, within the classrooms with higher average uses of mobile technology, the teacher-led functions are negatively correlated with students' physics achievement and interest. This result suggests that teachers should not heavily use teacher-led functions in physics learning. However, if it is used within the range of reasonable frequency, higher use of teacher-led functions still positively predicts student physics achievement and interest. This is likely due to the fact that teacher-led functions are mostly an instructor-centric pedagogy (Ifenthaler & Schweinbenz, 2013), an approach that, in the constructivist framework, is regarded as less effective in supporting students' construction process, as students are only passively

affected by the mobile technology. In other words, teacher-led functions rarely actively engage students with the use of mobile technology and therefore may fail to facilitate students' knowledge construction. For example, if teachers only screen display information on student tablets, students might just read information instead of thinking, and thus no contribution is made to their knowledge construction (Karlson et al., 2010). However, if the technology is used properly (e.g., limit the using frequency), it might help teachers to better understand their students' progression or save time, thus helping the teachers scaffold their students' knowledge construction.

This study has some limitations that suggest caveats when we generalize the findings. First, we proposed an STC model before the empirical study, but the current data was limited to high school students, to physics classrooms, and to a specific multifunctional mobile app. Thus, an inference might be made that the model is applicable to other grade levels, other STEM subjects, and even other types of educational technology but without empirical evidence. Future studies could continue to explore the generalizability of this model by collecting diverse data. Second, by using the quantitative method, this study examined the using frequency and impacts of the three categories of mobile functions. We carefully interpret the result to uncover the potential causal mechanics. However, a quantitative study alone is insufficient to produce a convincing causal inference. For example, the student-led functions were found to be of the greatest effect size. This might also be explained by the fact that the students who used more student-led functions were potentially more involved in physics learning. Future research should employ qualitative methods, mixed methods, or experimental design to investigate some of our speculations in the above discussion and to support the mechanics with respect to how the categories of mobile learning functions impact students' achievement and interest.

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Compliance with Ethical Standards

Conflict of Interest Author Xiaoming Zhai declares that he has no conflict of interest. Author Min Li declares that she has no conflict of interest. Author Siwei Chen declares that she has no conflict of interest.

Ethics Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

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